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TEST EFFECTIVENESS TREND OBSERVATION

EMC Testing Failures - Waivers Versus Design Changes

References: 1. TETA TO-0007 "Relationship of Engineering Changes to Waivers in the Resolution of EMC-Test-Related Problems," April 15, 1992.

CONCLUSIONS:

A large number of failures that occur during electromagnetic compatibility (EMC) testing result in waivers instead of design changes. These failures generally involve exceeding the allowable emissions over a very narrow bandwidth at frequencies that do not cause performance anomalies.

The current practice of using the military standard test specifications as a baseline for EMC requirements provides a high degree of conservativism. Early EMC involvement in hardware development testing can provide the necessary information to establish "realistic" mission specific requirements for radiated and conducted emissions and thus minimize waivers.

BACKGROUND:

Electromagnetic compatibility (EMC) in spacecraft is concerned with the generation, transmission and reception of electromagnetic energy. These three aspects of the EMC problem form the basic framework of any EMC design. Interference may occur if an energy transfer to a receptor causes it to behave in an undesired manner. Transfer of energy to a receptor causes electromagnetic interference (EMI) only if the received energy is of sufficient magnitude and/or spectral content at the receptor input to cause the receptor to behave in an undesired fashion. The processing of the received noise energy by the receptor is an important aspect as to whether interference will actually occur. See the appendix for more details of the requirements.

The most effective way to avoid EMI problems is to suppress the emissions at its source. To that end, requirements have been established by the Department of Defense and NASA that limit the amount of electromagnetic energy (noise) that a spacecraft assembly can emit (*emissions*). Furthermore, the requirements also specify the minimum levels of electromagnetic energy that a spacecraft assembly must be able to tolerate (*susceptibility*). These requirements are embodied in one major EMC standard: MIL-STD-461/462 (Electromagnetic Compatibility Requirements/Measurements). The EMC requirements in MIL-STD-461/462 are divided into four major parts: *conducted emissions*, *conducted susceptibility*, *radiated emissions*, and *radiated susceptibility*. In addition, electrostatic discharge (ESD) requirements are imposed on space systems because of spacecraft charging resulting from the space plasma environment. Grounding topology is also an important part of EMC requirements. The magnetic characterization of spacecraft assemblies is

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usually driven by the science payload and the requirements vary with the mission. Typically this involves the magnetic mapping of an assembly to determine its equivalent magnetic dipole.

The most cost effective method for dealing with EMC requirements is the implementation of sound design practices.

DISCUSSION:

The ob ective of this analysis is to determine the reasons that waivers for EMC tests are more abundant than those resulting from any other environmental tests. (see Ref. 1). In this search we investigated the number of Problem Failure Reports (PFRs) generated and waived in each of the following EMC tests: conducted emissions, radiated emissions, conducted susceptibility, radiated susceptibility, isolation/grounding, and magnetic characterization.

This investigation of EMC PFRs was done for Voyager and Galileo since these two ma or missions contained the largest number of PFRs. The causes for all EMC PFRs were investigated and are summarized in Tables 1 and 2.

In addition, the waivers resulting from PFRs listed in Tables 1 and 2 were reviewed. The Voyager and Galileo pro ects generated the largest numbers of waivers. For each EMC type of test the number of waivers generated and the rationale for such waivers were recorded. These results are shown in Tables 3 and 4.

Tables 1 and 2 show that the Voyager spacecraft generated 75 EMC PFRs and Galileo generated 146. For Voyager 66% of all PFRs were related to conducted and radiated emissions specification violations (including magnetics) and for Galileo such PFRs accounted for 77%. In other words, for Voyager there were twice as many PFRs for emissions failures as susceptibility failures. For Galileo there were three times as many emissions failures as susceptibility failures.

Tables 3 and 4 show that similar results were obtained for waivers. For Voyager, magnetic emissions requirements violations accounted for 50% of all waivers and 40% were for tests that were never performed due to schedule constraints. Hence, if you consider the results of Table 1, 50% of all PFRs for Voyager were waived because magnetic emissions which were not of concern from the EMI point of view since their magnitude levels were below the susceptibility level of Voyager's magnetometer. This is inherent in the process necessary for the control of the magnetic cleanliness of the spacecraft. Initial requirements must be established on a worse case basis and, as test data becomes available, relaxation through the use of waivers may be possible since not all assemblies may require their full allocation.

For Galileo 74% of all generated waivers were related to emissions requirement violations while 26% accounted for hardware anomalies caused from susceptibility testing. If we consider the results of Table 2, 56% of all PFRs for Galileo were waived because radiated and conducted emissions were not of concern from the spacecraft view. In the specific case of the Galileo spacecraft it must be stated the considerable number of PFRs were attributed to very stringent Space Shuttle radiated/conducted emissions requirements for payloads. The disposition of many of the PFRs resulted in waiving of the requirements because most of Galileo systems would be "turned-off" during launch.

In summary the analysis of these results show the following items:

1. A ma ority of EMC **PFRs** were generated as a result of violations of *emissions* requirements.

2. The ma ority of **waivers** were also generated against *emissions* requirements. Even though EMC specification requirements were violated (i.e emissions above specification limits) it was determined that the resulting excessive interference would cause very little (if any) anomalies on the spacecraft.

3. PFRs from *susceptibility* tests resulted in very few waivers.

The radiated and conducted emission measurements are often waived because they do not reflect the true pro ect needs (i.e. they are not "tailored"). The question then arises, "Why not tailor the requirements?". The answer is two-fold. First, in many cases, the requirements are established by an external source (e.g. the STS or other launch vehicle requirements on payloads) and the hardware supplier does not participate in the requirements process. In this case the only recourse is to implement the waiver process for test failures. The second reason for not tailoring requirements is related to the delivery of hardware to other agencies which establish the requirements for other programs. In the field of EMC, the requirements are complex, and the various practitioners often resort to generic requirements based on military standards (MIL-STD-461/462, MIL-STD-1541, etc.). This approach permits easier understanding of the requirements, and very importantly, easier and more uniform implementation of the testing. Especially for the radiated requirements, the design is not very sensitive to the specific requirements, so the imposition of generic specifications is an acceptable method. Additionally, the test results based on the generic requirements provide data that is necessary for an adequate system design analysis; this is a very important consideration. The data base provided by the generic testing is frequently of benefit to evaluating downstream decisions related to unanticipated changes in design or mission environment. It should be noted that if mission specific requirements are more severe than the generic, the specific needs are incorporated into the generic.

There is a difference between radiated emission and radiated susceptibility results. The generic MIL STD radiated emission requirements, especially, tend to be severe and often have large margins built into them. This is because they were based on general requirements for radio receivers, and most spacecraft only need small regions of the frequency spectrum to be clear. In the case of the Space Shuttle, its multipurpose mission role and the manned element requires a very conservative approach to requirements. Therefore, the requirements often result in test failures that are usually unimportant to specific NASA missions and can therefore be waived.

The radiated susceptibility requirements, by the same reasoning, are often excessive. However, most well designed electrical and electronic equipments are not susceptible, and thus fewer test failures occur. When test failures do occur, often they will occur at a frequency that is not significant to the mission and thus can be waived.

Note that many magnetics requirements were often waived not because the requirements were wrong, but for another reason. Initially DC magnetic emission requirements, or dipole allocations, are established on a worse case basis and, as hardware is built and magnetically characterized, reallocation is often possible and relaxation of requirements

through waivers can be accommodated. This involves an analytical process which assures that the total system requirements are met for the science payload. The waiver process provides a formal tracking of the acceptable variations.

A logical question arises with respect to the EMC emissions and susceptibility PFRs. How many PFRs would have been eliminated if, for example, the radiated emissions requirements for a particular spacecraft were lowered by 10 dB? Unfortunately the answer to such a question is rarely found on a PFR form. Because the level of effort required to review the actual EMC test data would be beyond the scope of this study, an effort was made to extract representative information from the Test Results Summary Form (TRSF) database for the Voyager program. This database was searched for all EMC tests except DC isolation and magnetics. The TRSFs for a total of 47 units were reviewed and there was insufficient information provided to establish the impact of a specific relaxation of the test requirements.

Table 1. PFR Statistics for Electromagnetic Compatibility Tests
Spacecraft Mission: Voyager

EMC TEST	Number of EMC PFRs	% of Total	Rationale(s) for PFR
Conducted Emissions	14	19	Emission measurements above spec. limits
Conducted Susceptibility	6	8	Hardware susceptible to field levels at certain frequencies
Radiated Emissions	18	24	Electric field emission measurements above spec. limits
Radiated Susceptibility	10	13	Hardware susceptible to field levels at certain frequencies
Magnetics Emissions	17	23	Max. magnetic fields spec. limits are exceeded
Isolation & Grounding	10	13	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.
Total	75	100	

Table 2. PFR Statistics for Electromagnetic Compatibility Tests
Spacecraft Mission: Galileo

EMC TEST	Number of EMC PFRs	% of Total	Rationale(s) for PFR
Conducted Emissions	38	26	Emission measurements above spec. limits
Conducted Susceptibility	9	6	Hardware susceptible to field levels at certain frequencies
Radiated Emissions	62	43	Electric field emission measurements above spec. limits
Radiated Susceptibility	16	11	Hardware susceptible to field levels at certain frequencies
Magnetics Emissions	12	8	Max. magnetic fields spec. limits are exceeded
Isolation & Grounding	9	6	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.
Total	146	100	

Table 3. Waiver Statistics for Electromagnetic Compatibility Tests
Spacecraft Mission: Voyager

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Conducted Emissions	2	10	#40970 & 40973-- Eliminate test from a particular assembly	Schedule constraints.
Conducted Susceptibility	2	10	#40970 & 40973-- Eliminate test from a particular assembly	Schedule constraints.
Radiated Emissions	2	10	#40970 & 40973-- Eliminate test from a particular assembly	Schedule constraints.
Radiated Susceptibility	2	10	#40970 & 40973-- Eliminate test from a particular assembly	Schedule constraints.

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Magnetics	10	50	#40518 & 40772--Static magnetic field emissions above specs. #40788--Demagnetization test not applicable to memory hardware. #40792--Static magnetic field emissions above spec. #40801--Demagnetization of assembly decreased magnetic fields. After energizing, field magnitude increased above specs. #40816--Not to demagnetize the assembly. #40854 & 40816--Residual static magnetic field is above specs. #40893--Allow memories to be remove before the process of demagnetization. #40979--Allow installation of assembly without magnetic fields tests.	Magnetic properties of assembly are inherited in design. Memory can be destroyed. Will not interfere with magnetometer susceptibility threshold. Extrapolated magnetic field levels to magnetometer distance is below magnetometer sensitivity. Once done it should not be done again unless it leaves JPL. Compensation of static magnetic field does not always works well for such small margin above specs. Memories can be destroyed. Inherited hardware which was previously tested.

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Isolation & Grounding	2		#40806--Allow isolation test outside EMC room #40560--Allow isolation of less than 400 pF	Test does not need shielded room Measured isolation is close to the one required
Totals	20	100		

Table 4. Waiver Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Galileo

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Conducted Emissions	7	20	#33546--Emissions in power lines allowed to exceed specs. #33547--Emissions in signal lines allowed to exceed specs. #33674--Emissions in power lines allowed to exceed specs. #33680--Transient emissions in power lines allowed to exceed specs. #33691--Emissions in power and signal lines allowed to exceed specs. #33701 & 34088--Emissions in power lines allowed to exceed specs.	Assembly performs well in spacecraft. Assembly does not interfere with spacecraft. Assembly performs well in spacecraft. Assembly does not interfere with spacecraft. Emissions are caused by set up of support equipment during test. Emissions are caused by set up of support equipment during test. Current ripple will not affect other instruments in the same power bus. Interference attributed to coupling with support equipment during test.

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Conducted Susceptibility	2	6	#33664--Assembly susceptible to ripple test. #33767--Assembly susceptible to transient test.	Interference is tolerable by assembly. Interference produce minor interferences in assembly.
Radiated Emissions	9	26	#33618, 33764, 34050, 33795 & 33645--Electric field emissions above specs. #33671, 33750 & 33795--Electric field emissions above specs. #33779--Electric field Emissions above specs.	Emissions from assembly will not interfere since they are well below Shuttle/Centaur susceptibility levels. Rework will be too costly and time consuming. Interference levels poses no problems to other assemblies. Attempt to reduced fields can be costly. Emissions come from interference of support equipment.
Radiated Susceptibility	7	20	#33588, 33675, & 34021--Electrostatic discharge susceptibility observed on assemblies. #33656, 33665, 33766 & 33970--Interference detected by assemblies.	Small perturbations caused can be survived by assemblies. Minor anomalies are detected in the assemblies but interferences are minor and survivable.

EMC TEST	Number of Waivers	%	Waiver Requested	Rationale(s) for Waiver
Magnetics	10	28	#33473, 33526, & 33765--Low frequency radiated magnetic fields above specs. #33590, 33685, 33692 & 33933--Low frequency radiated magnetic fields above specs. #33651, 33763 & 33933--Static magnetic fields emissions above specs.	Emissions will have very little effect on other assemblies. Retrofit will be too costly. Emitted fields will not affect magnetometer sensor and other assemblies. Adding shields will be too costly. Inherited voyager design. Magnetic compensation was not effective for such a small margin above specs. Magnetometer science requirements are met without compensation. Retrofit too costly.
Isolation & Grounding	0	0		
Totals	35	100		

APPENDIX

Conducted Emissions: The intent of the conducted emission requirements is to restrict the DC noise current passing out through the spacecraft assemblies' power/signal cables. The reason for this is that these noise currents cause noise voltages on the common power/data bus of the spacecraft and can affect other systems and instruments which feed from the same power/data bus (conducted EMI).

Radiated Emissions: The intent of the radiated emissions requirements is to restrict the unintentional radiated levels of electric and magnetic fields that are produced by any spacecraft system, subsystem or instrument. The rationale for this is that these emissions can interfere with the spectrum of many receiver circuits or disrupt other sensitive circuitry.

Conducted Susceptibility: The intent of the conducted susceptibility requirements is to verify that noise entering power and signal cables will not interfere with the normal operating conditions of spacecraft systems.

Radiated Susceptibility: The intent of the radiated susceptibility requirements is to ensure that the spacecraft system, subsystem and instrument will operate properly in an environment where intentional and unintentional radiators of electromagnetic energy are present.

Grounding: The intent of the grounding and isolation tests is to verify that power circuits are DC isolated from chassis ground or circuit common according to given specification requirements. Generally, the requirements involve grounding all of the spacecraft systems to a single point (single point grounding) in order to avoid EMI grounding problems such as: a) ground loops, b) common impedance coupling.

Magnetic Characterization: The intent of the magnetic characterization, or mapping, is to measure the magnetic dipoles (i.e dipole moment) of certain spacecraft assemblies and investigate how the magnitudes of such dipoles can interfere with magnetometers, plasma wave devices, and other instruments that may be sensitive to ambient magnetic fields.